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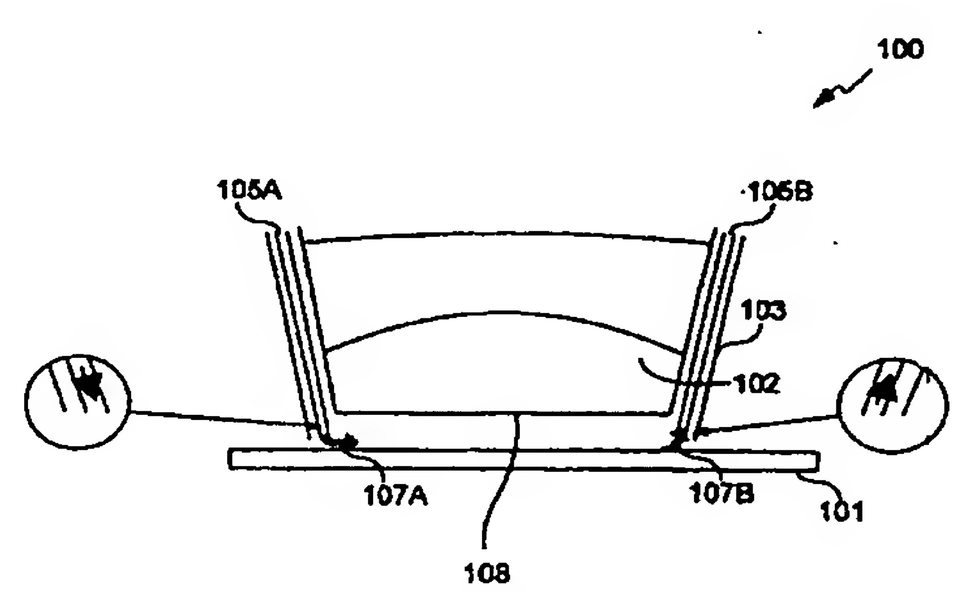
[54] 发明名称 浸入式光刻系统及使用微通道喷嘴的方法

[57] 摘要

一种液体浸入式光刻系统包含一曝光系统，其以电磁辐射光一基底并包含一投影光学系统，其将电磁辐射对焦于该基底上。一液体供给系统提供于投影光学系统与基底之间的液体流动。多个选用微喷嘴系被安排在该投影光学系统的一侧的外围上，以提供在基底曝光区域中的液体流动的实质均匀的速度分布。



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1. 一种液体浸入式光刻系统，包含：

曝光系统，其以电磁辐射曝光一基底并包含一投影光学系统，该投影光学系统将电磁辐射对焦在基底上；

液体供给系统，其在投影光学系统与基底之间提供液体流；以及

多个微喷嘴，安排在该投影光学系统的外围旁，以在基底及投影光学系统之间提供液体流的基本均匀的速度分布。

2. 根据权利要求 1 的液体浸入式光刻系统，其中所述多个微喷嘴包含多个变化长度的管。

3. 根据权利要求 1 的液体浸入式光刻系统，其中所述多个长度变化的管提供速度分布，其补偿不均匀性。

4. 根据权利要求 1 的液体浸入式光刻系统，其中所述液体供给系统包含：

输入通道，用以输送液体进入第一充填室；

第一漫射屏，该液体可以经过它流入第二充填室；

其中该液体可以然后流入微喷嘴。

5. 根据权利要求 4 的液体浸入式光刻系统，其中所述液体供给系统还包含：

第二多个微喷嘴，用以由曝光区移除该液体进入第三充填室；

第二漫射屏，经由该漫射屏，液体流入第四充填室；及

输出通道，液体经由该通道循环。

6. 根据权利要求 1 的液体浸入式光刻系统，其中所述投影光学系统包含一外壳，在外壳和基底之间有一气封。

7. 根据权利要求 6 的液体浸入式光刻系统，其中该外壳包含多个连接至该气封的环带通道，负压经由该气封维持在该曝光区旁，以移除残留液体。

8. 根据权利要求 1 的液体浸入式光刻系统，其中所述多个微喷嘴直径在 5 微米至 5 毫米之间。

9. 根据权利要求 1 的液体浸入式光刻系统，其中所述多个微喷嘴为狭缝形。

10. 根据权利要求 1 的液体浸入式光刻系统，其中上述多个微喷嘴的至少一部份包含一扩大口部份，进入在基底与投影光学系统之间的一区域。

11. 根据权利要求 1 的液体浸入式光刻系统，其中所述液体流的方向为可逆的。

12. 根据权利要求 1 的液体浸入式光刻系统，其中所述液体供给系统包含至少三个通道，其中液体可以流经该通道。

13. 根据权利要求 1 的液体浸入式光刻系统，其中所述液体供给系统补偿速度分布中的不均匀。

14. 一种液体浸入式光刻系统，包含：

曝光系统，其以电磁辐射曝光在一基底上的曝光区并包含一投影光学系统；

提供机构，用以在该投影光学系统与该曝光区之间提供一液体流；以及

第一微喷头，在该投影光学系统的一侧，其当液体流出现在曝光区时，提供具有希望的速度分布的液体流。

15. 根据权利要求 14 的液体浸入式光刻系统，其中所述微喷头包含多个具有变化长度的管。

16. 根据权利要求 15 的液体浸入式光刻系统，其中所述多个长度变化的管提供一速度分布，其补偿不均匀。

17. 根据权利要求 14 的液体浸入式光刻系统，还包含一液体供给系统，其包含：

输入通道，用以输送该液体进入第一充填室；

第一漫射屏，经由该漫射屏，流体可以流入第二充填室，

其中该液体经由该微喷头流入该曝光区。

18. 根据权利要求 15 的液体浸入式光刻系统，其中所述液体供给系统还包含：

第二微喷头，用以自曝光区移除液体进入第三充填室；

第二漫射屏，液体经由该漫射屏可以流入第四充填室；及

输出通道，液体可以经由该通道循环出曝光区。

19. 根据权利要求 14 的液体浸入式光刻系统，其中所述投影光学系统包含一外壳，在外壳与该基底之间具有一气封。

20. 根据权利要求 19 的液体浸入式光刻系统，其中所述外壳包含多个通道，负压经由该通道维持在曝光区旁，以移除残留液体。

21. 根据权利要求 14 的液体浸入式光刻系统，其中所述微喷头具有多个微喷嘴，其直径在 5 微米至 5 毫米之间。

22. 根据权利要求 21 的液体浸入式光刻系统，其中至少部份微喷嘴包含一扩大口部份，其进入该曝光区。

23. 根据权利要求 21 的液体浸入式光刻系统，其中所述多个微喷嘴为狭缝形。

24. 根据权利要求 14 的液体浸入式光刻系统，其中所述液体流的方向为可逆的。

25. 根据权利要求 14 的液体浸入式光刻系统，其中所述液体供给系统包含至少三个通道，液体可以流经该通道。

26. 根据权利要求 14 的液体浸入式光刻系统，其中所述微喷头补偿由于扫描造成的速度分布的不均匀。

27. 一种液体浸入式光刻系统，包含：

曝光系统，其以电磁辐射曝光一基底上的曝光区并包含一投影光学系统；

在该投影光学系统与该曝光区之间的液体流，它具有一速度分布，以补偿该曝光系统与该基底的相对运动。

28. 一种液体浸入式光刻系统，包含：

曝光系统，其以电磁辐射曝光一基底上的曝光区并包含一投影光学系统；

多个微喷嘴，在该投影光学系统的一透镜外围旁，该微喷嘴在曝光区提供一液体流。

29. 一种液体浸入式光刻系统，包含：

曝光系统，其以电磁辐射曝光一基底并包含一投影光学系统，该投影光学系统将该电磁辐射对焦至该基底上；

液体供给系统，其在该投影光学系统与该基底之间提供液体流，

其中该液体流的方向可以改变，以补偿基底移动的方向。

30. 根据权利要求 29 的液体浸入式光刻系统，还包含多个微喷嘴，安排在该投影光学系统的外围，以提供在基底与该投影光学系统之间的液体流的基本均匀的速度分布。

31. 根据权利要求 30 的液体浸入式光刻系统，其中该多个喷嘴包含多个变化长度的管。

32. 根据权利要求 31 的液体浸入式光刻系统，其中所述变化长度管提供一速度分布，用以补偿不均匀。

33. 根据权利要求 29 的液体浸入式光刻系统，其中该液体供给系统包含：

输入通道，用以输送液体进入第一充填室；

第一漫射屏，液体可以经由该漫射屏流入第二充填室，

其中该液体可以然后流入微喷嘴。

34. 根据权利要求 33 的液体浸入式光刻系统，其中该液体供给系统还包含：

第二多个微喷嘴，由该曝光区去除液体进入一第三充填室；

第二漫射屏，液体经由该漫射屏流入第四充填室；及

输出通道，液体经由该通道加以循环。

35. 根据权利要求 29 的液体浸入式光刻系统，其中该液体供给系统补偿速度分布中的不均匀。

36. 一种曝光一基底的方法，包含步骤：

使用一投影光学系统，投射电磁辐射至该基底上；

在投影光学系统与该基底之间输送液体流；以及

控制液体流的速度分布，以提供基本均匀的速度分布。

37. 根据权利要求 36 的方法，还包含步骤：使用一气体供给系

统，自该基底移除过量液体。

38. 根据权利要求 36 的方法，还包含步骤：逆转该液体流的方向。

39. 一种曝光一基底的方法，包含步骤：

使用一投影光学系统，将电磁辐射投射至基底上；

在该投影光学系统及基底之间输送液体流；及

改变该液体流的方向，以补偿在基底移动的方向中的变化。

40. 根据权利要求 39 的方法，还包含步骤：使用一气体供给系统，由基底移除过量的液体。

浸入式光刻系统及使用微通道喷嘴的方法

技术领域

本发明涉及液体浸入式光刻术，更明确地说，涉及用以控制于浸入式光刻系统中的液体流动的速度分配的方法与系统。

背景技术

光刻术的实际限制假定为发生影像的媒介为空气。这实际限制系由有效波长公式 $\Lambda_{eff}=\frac{\lambda}{2\cdot n\cdot NA}$，其中 λ 为入射光波长，NA 为投影光学系统的数值孔径，及 n 为媒介的折射率。现在，藉由引入液体（替代空气）于投影光学系统的最后透镜组件与一被成像的晶片之间，该折射率改变（增加），藉以藉由降低光源的有效波长，而增加分辨率。降低一光源的波长自动地完成更细微的分辨率。以此方式，浸入式光刻术例如藉由有效地降低 157nm 光源为 115nm 光源波长而变成有吸引力，藉以增加分辨率同时也使得现行工业所惯用之相同光刻工具可以完成更临限的印刷。

同样地，浸入式光刻术也可以将 193nm 光刻术向下推至 145nm。于理论上，例如 193nm 工具的较旧技术现在仍可以使用。同时，理论上，很多 157nm 光刻术的困难，如大量的 CaF_2、硬薄膜、氮冲洗等也可以避免。

然而，尽管浸入式光刻术有前途，但仍有若干问题，这些问题使得浸入式光刻系统不能商业化。这些问题包含光学失真。例如，在浸入式光刻扫描时，足够 g-负载被建立，而干扰了系统效能。这些加速负载可能引起与透镜的振动、流体剪切交互作用，因而，造成光学劣化。在浸入式光刻术的透镜流体环境内的上下扫描动作可能在光学组件上产生变化的流体剪切力。这可能造成透镜振动不稳定，而造成光

学“褪色”。其它的速度分布不均匀也可能造成光学失真。

发明内容

本发明有关在曝光区内液体的近均匀速度分布的浸入式光刻系统，以实质地免除相关技术中之一或多个问题及缺点。

本发明提供一种液体浸入式光刻系统，其包含一曝光系统，其以电磁辐射曝光一基底并包含一投影光学系统，其将电磁辐射对焦于基底上。一液体供给系统提供液体流于该投影光学系统与基底之间。多个微喷嘴系可选用地安排在投影光学系统的一侧外围上，以提供于基底被曝光的区域中的液体流的实质均匀速度分布。

于另一方面中，提供一液体浸入式光刻系统，包含一曝光系统，其以电磁辐射曝光一基底上的曝光区及包含一投影光学系统。一液体流系产生在投影光学系统及该曝光区之间。一微喷头系在投影光学系统的一侧上，并提供曝光区以想要速度分布的液体流。

本发明的其它特性及优点将说明于以下的说明中。本发明的其它特性及优点将为本领域技术人员基于以下说明及本发明的教导加以了解。本发明的优点将藉由说明及其申请专利范围与附图加以了解及体现。

应可以了解的是，前述一般说明及以下的详细说明作为例示目的，并想要以对本发明所主张者提供进一步的说明。

附图说明

包含以提供对本发明例示实施例的进一步了解及构成本说明书一部份的附图例示了本发明的实施例，其与说明一起作用以说明本发明的原理。

图 1 为一基本液体浸入式光刻组件侧视图。

图 2 为图 1 之组件平面图。

图 3 为相比较于图 1 的基本液体浸入式光刻组件，其中的液体流方向相反。

图 4 显示液体浸入式光刻系统的其它细节。

图 5 为图 4 的结构的部份立体图。

图 6 为一例示液体速度分布。

具体实施方式

现参考本发明的实施例，其例示于附图中。

于浸入式光刻术中的一主要问题为液体流的不均匀，尤其是在垂直方向中的梯度。该不均匀主要是由于其接近一移动面，液体系与该表面（例如一晶片的表面）接触。例如，于扫描时，该晶片相对于曝光系统移动，在接近其表面建立一“拖曳效应”。因此，液体动力学原理指出在这些区域中，相对于晶片表面的流体速度为零（或至少接近零），而当远离晶片表面时，流体速度为最大。同样地，相对于透镜底面的流体速度为零。这些流体速度变量被称为“边界层”速度分布。这些作用的组合在液体中，产生一剪切力，其建立了两倍的光学失真问题：1）于孔径硬件上，惯性振动力的产生（造成光学失真），及 2）在流体内形成速度的条纹，这进一步造成光学失真。

另外，液体注入曝光区中也同时提供在速度分布上可能额外的不均匀性。例如，若干条纹可以存在于该流体中，进一步降低了曝光品质。同样地，因为光学失真引入曝光程序之故，所以，空气泡、光学流体振动、或于液体流中的涡流也降低光刻系统的整体效能。因此，由光刻系统中的成像品质观点看来，有关速度分布不均匀是重要的。于理想下，液体速度分布是在每一地方都应均匀。

图 1 为本发明的液体浸入式光刻系统的方块图。如图 1 所示，一光刻工具的投影光学系统 100 包含一透镜 102（其典型由多个透镜组件构成）。于此图中，透镜 102 具有一平坦底面 108，但也可以不必如此。透镜高度 409（见图 4）可以调整，以维持对晶片 101 的一特定距离。

投影光学系统 100 同时也包含一外壳 103（只有下部份被显示）。外壳 103 包含一环形液体通道 105A、及选用地，包含多个其它此等通

道 105B 等等。液体流经通道 105（于此图中，流入经通道 105A，并经由通道 105B 流出）。箭头 107A、107B 表示当晶片 101 被扫描于整个投影光学系统 100 的视域中时，在晶片 101 上的液体流动方向。

图 2 例示图 1 中所述的结构的仰视图。如图 2 所示，一通光孔径区 216 定义投影光学系统 100 及透镜 102 的曝光区。各种箭头 107A-107D、211A-211D 例示在任意给定时间中可能的液体流方向。可以由图 2 看出，外壳 103 也包含若干加压室 215A-215D。每一加压室 215 也被称为“充填室”。因此，充填室 215 如下所述作为一压力源。可以了解的是，当不发生曝光或晶片 101 被更换时，液体流可以完全地关闭。

再者，如图 2 所示，外壳 103 的下部份可以被分为若干区。于此图中，可以为间隙 217A-217D 所分割开为四个此种区（四分）。可以了解的是，这些区的数目可以多于或少于四个，但于多个应用中，期待四分系为一最佳数。例如，对于沿着一轴的动作，将外壳 103 分割为两区也就足够了。对于 X-Y 动作，四个区（四分）是较佳的。为了更大地控制，也可能需要八个区。此分区允许对液体流方向的控制，这将如下所详述。控制液体流方向使得其可能对抗在透镜 102 上的机械应变，因此，在 X 方向中的流动分布（特别是在一步骤中）可能与在 Y 方向（特别是在一扫描中）中的流动分布不同。

图 3 例示与图 1 相同的结构，除了液体流动方向相反。可以为本领域技术人员了解的是，于实际光刻系统中，将液体流方向反转的能力是重要的，因为晶片动作的方向通常并不只限定于一方向。同样地，可以为本领域技术人员所了解，如图 2 中，晶片 101 可以移动于 X 方向及 Y 方向中。因此，将外壳 103 分为四分允许液体流方向被调整，用于晶片移动的任何方向。

图 4 例示本发明之一实施例的其它细节。如图 4 所示，透镜透镜 102 被安装在外壳 103 中。外壳 103 具有环形通道 105A、105B，液体经由该等通道流进出一液体供给系统（于这些图中未显示）。由通道 105A 中，液体然后进入一第一大充填室 215A。其然后流经一漫射屏

412A 进入一第一小充填室 414A（其是典型小于第一充填室 215A）。该漫射屏 412A 协助可能出现在第一大充填室 215A 中的涡流及气泡。漫射屏 412 也作为一压力下降筛网。

第一小充填室 414A 也作为一压力室。由第一小充填室 414A，液体流经多个微通道喷嘴（微喷嘴）416A，其是安排呈一微喷头的形式。因此，藉由液体到达微喷嘴 416 的时间，在入口至所有微喷嘴 416 的压力为均匀的，及涡流及气泡已经由液体上实际移除。在微喷嘴 416 后，液体流入在透镜 102 下的通光孔径区 216，使得于透镜 102 及晶片 101 之间的空间被填满该液体。

于该通光孔径区 216 中，液体流于高度上是均匀的，并没有涡流、气泡、条纹及其它会影响光学影像品质的不完美。

在通光孔径区 216 的另一侧上，液体再一次流经一组微通道喷嘴 416B 进入一第二小充填室 414B，经由一漫射屏 412B，进入一大充填室 215B 及离开通道 105B。

因此，于图 4 中，晶片 101 由左向右的相对移动，晶片 101 在液体上，建立"拖曳效应"。因此，液体流方向需要由右至左，以对抗"拖曳效应"，并造成实质均匀速度分布。

于图 4 中，420 表示在通光孔径区 216 中为晶片 101 移动所造成的有效流体流速分布。421 表示由微通道喷嘴 416 的抗注入流体分布，得到在透镜 102 与在通光孔径区 216 中的液体间之界面，接近净零之所得流体速度。

微通道喷嘴 416 同时也必须经常地更新（即更换）工作液体（其必须防止随着时间解离，因为受到密集电磁辐射的曝射可能破坏液体分子），以排除热梯度，造成折射率失真及影像品质劣化。避免由于定流量的液体（例如水）的解离为另一优点。在短曝光波长时，水可以解离于约 $2.86J/cm^2$RT 及正常 P 下降至 4.75×10^{-19}J 每分子。于 193nm，一光子承载 1.03×10^{-18}J。另外，保持液体更新允许维持液体的定温。液体可以于曝光时，或于曝光间更新。

微喷嘴 416 同时也作为一缓冲器，以对抗于光学件与液体间的惯

性剪切力。注意剪切力是由公式 $F=A\cdot\mu\cdot\frac{dv}{dx}$，其中 A 为面积，μ 为速度参数，x 为距离变量、及 v 为速度。在晶片 101 及透镜 102 间的典型 100 微米间隙中，剪切力大约 1 牛顿。这些剪切力的中和化是藉由惯性阻尼于透镜 102 及流体间的相对加速动作加以完成。这是藉由简单地在相反于扫描的方向中，建立流体动作加以完成。微通道喷嘴 416 也作为一缓冲器，以对抗于光学件与流体间的惯性剪切力。

另外，外壳 103 包含一系统，用以供给气体以由晶片 101 移除过量的液体。外壳 103 包含一供给侧环带 406A，用以气体由气体供给系统（未示于图 4 中）流动；一气封 410A，其桥接至晶片 101 的距离并完成一“刮板”，以包含及移除过量液体，及一回来侧气体流出环带 405A（过量液体经由该处加以移除）。过量液体可以经由送回侧气体流出环带 405A 与排出气体加以移除。一类似结构可以在外壳 103 的相对四分之一中找出，如图 4 的左侧所示。气体供给系统配合液体供给系统动作，只有液体流出现时，当有液体流动于通光孔径区 216 时，随后，气体供给系统需要被用上。

于图 4 中，应注意，晶片由左向右移动时，液体流是在通道 105A“内”，及在通道 105B“外”。当扫描方向逆转时，液体流也逆转。

图 5 显示图 4 的微喷嘴结构区的部份等角图。通道 105 A-105D（未示于图 5 中）是连接至外管 507A-507D，液体是经由这些外管加以供给。同样地，虽然未示于图中，但环带 405、406 也可以连接至管状气体联结管。

图 6 为可以用于本发明的液体排出速度分布例。可以为本领域技术人员所知，一“自然”速度分布是随着图 4 的高度为不均匀，而是具有一垂直梯度，这可能造成光学失真。为了补偿此自然梯度，可以使用不同长度的管（微喷嘴 416），如图 6 所示。于图 6 中，微通道长度范围由最大值 L_1 至一最小值 L_2，造成显示在图 6 左侧所示的微喷嘴 416 的出口处的速度分布。微喷嘴 416 愈长，则由特定喷嘴的液体输出速度愈低。再者，如果需要对速度分布作进一步控制，则微喷嘴 416 本身可能具有不同直径。注意，为了更进一步控制速度分布，微

喷嘴416的管并不必然平行于晶片101。

在典型系统中的晶片101上的液体高度大约100微米。由于较大高度造成需要控制较大量的速度分布，所以会造成需要更多微喷嘴416A。

因此，小心选择微喷嘴416的长度、直径及方向，在晶片101的通光孔径区216中的速度分布可以被控制，而造成在整个通光孔径区216区的相当均匀的速度分布，藉以改良曝光品质。本质上，由例如图6所示的结构所产生的速度分布可以“相反”于“自然”分布。因此，微喷嘴416的特性被调整，以造成实质均匀速度分布。

于扫描时，当液体再循环并注入于一方向时，晶片101移动于一相反方向。本发明的作用是中和化为扫描动作所造成的液体速度分布，造成在透镜102及液体间的惯性阻尼。换句话说，净作用为“零”净惯性及速度分布与动作无关。取决于液体流的方向，可以完成剪切力的降低或免除，或者是光学失真的降低。因此，浸入式光刻制程能执行由于定流体更新在峰值位准，避免了气泡、及缓冲了光流体振动。

注意虽然于充填室215中的液体可能具有涡流及气泡，但在其行经漫射屏412时，其流量为均匀。因此，在通过漫射屏412、充填室414及离开微喷嘴416后，液体流具有一想要速度分布，而不会有由条纹、光流体振动、涡流、气泡、及其它不均匀所造成的缺陷，因而改良了影像品质。

如上所述，透镜102的底面108并不必为平坦。也可能使用具有曲面底部表面108的透镜102，用以补偿适当安排微喷嘴长度、直径及方向之造成的速度分布不均匀，以完成一接近均匀速度分布。

微喷嘴416也可以使用传统光刻技术于硅材料上加以建构。于显微镜规格上，微喷嘴416组合由管构成的螺巢材料，这些管是以交错方式堆栈，以展现液压直径及长度的主要特征规格。微喷嘴416也可以具有扩大口，进入通光孔径区216中。

微喷嘴416的典型管形直径可以变化，例如由几微米到几十微米（例如5至50微米），在部份例子中，于直径多至5mm，及长度于约

10 至 100 直径。也可以使用其它长度及/或直径。圆喷嘴外的狭缝也可以使用。每单位面积的微喷嘴的数量也可以变化。

对于 193nm 成像，液体较佳为水（例如去离子水），但其它液体，例如环辛烷、Krypton®（Fomblin 石油）及过氟聚醚油也可以使用。

本发明对于一液体浸入式光刻系统有着若干优点。例如，于一步进及扫描系统中，穿透率被改良，因此，有较低的失真。于空气中灰尘微粒不能进入于透镜 102 及晶片 101 间的通光孔径区 216，因为液体本身并不包含任何灰尘，及液体的出现会对曝光时出现在通光孔径区 216 中的灰尘的一种阻障。较佳地，液体在晶片 101 被加载一晶片台后被带入，及在晶片 101 被卸载前被移除。这最小化灰尘及微粒污染。另外，于晶片交换时，防止液体溢出的方法也有好几种，及本发明并不限定于上述的一种。

为扫描动作所引入的流体速度分布被中和化，造成在透镜 102 及剪切流体间的惯性阻尼。除了作为惯性阻尼外，微喷嘴 416 也作用以更新工作流体容积，藉以免除由于光源造成的热梯度所引起的折射失真。微喷嘴 416 的另一优点为其于容积更新时不利于气泡的形成。同时，这些微喷嘴 416 的大小防止气泡的形成，气泡的形成损及了很多传统更新技术。所有这些优点允许使用现行光刻工具及波长，以在一半导体表面上，定义更小的特性。

结论

虽然本发明的各种实施例已经说明如上，但应了解的是，这些是作为例示，而不是限定用。可以为本领域技术人员所了解，各种于形式及细节上的变化可以在不脱离本发明的精神及范围下加以完成。

本发明已经在功能方块图及方法步骤的协助下，例示了其特定功能及关系。这些方块图及方法步骤的边界已经任意定义。其它边界也可以定义，只要其特定功能及关系被适当地执行。同时，方法步骤的顺序也可以再排列。这些替代边界也在本发明的精神及范围内。本领

域技术人员可以了解，这些方块图可以由分立组件、客户指定集成电路、处理机执行适当软件等等或其组合。因此，本发明的范围应不为上述例示实施例所限定，应依据以下的权利要求书及其等效加以定义。

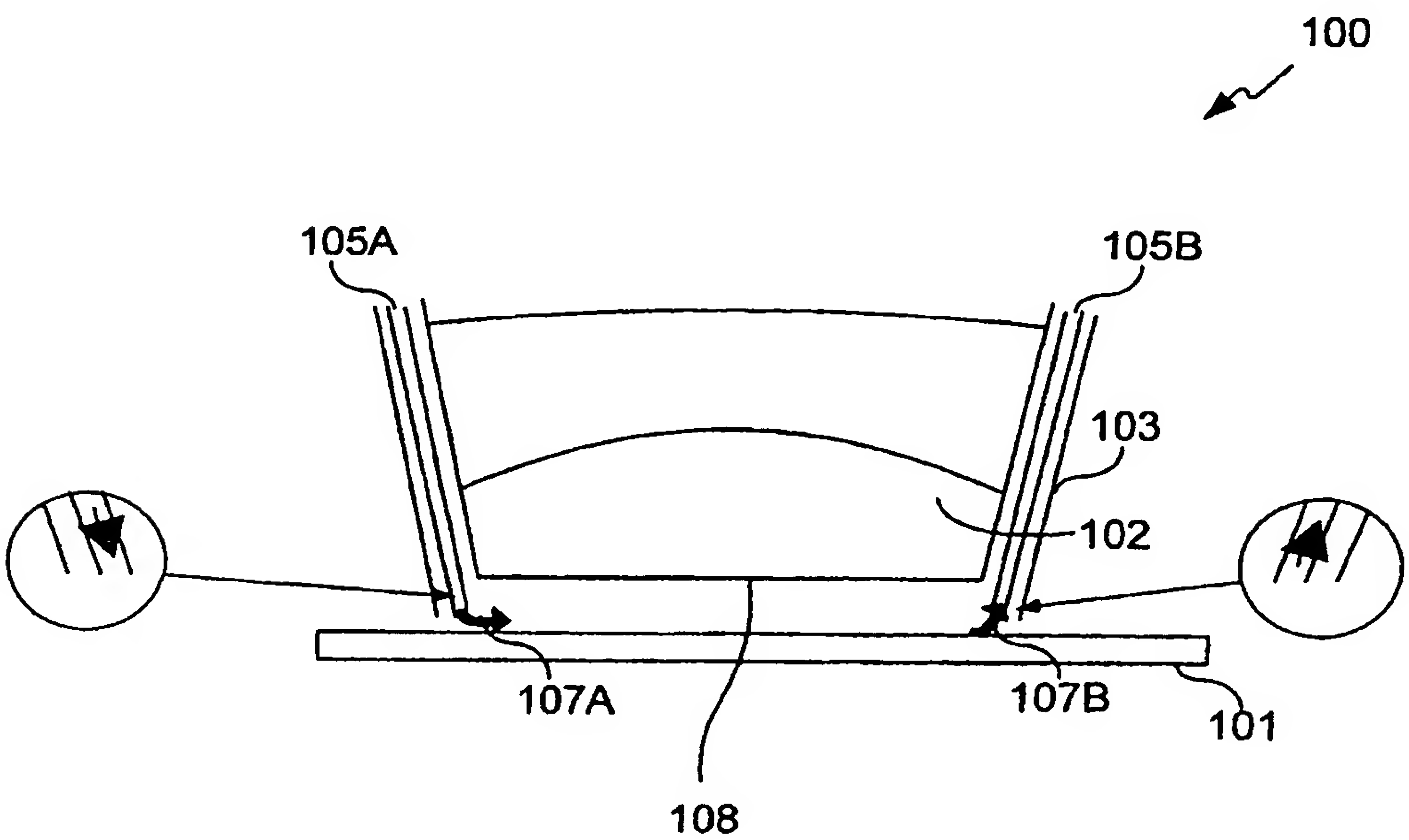
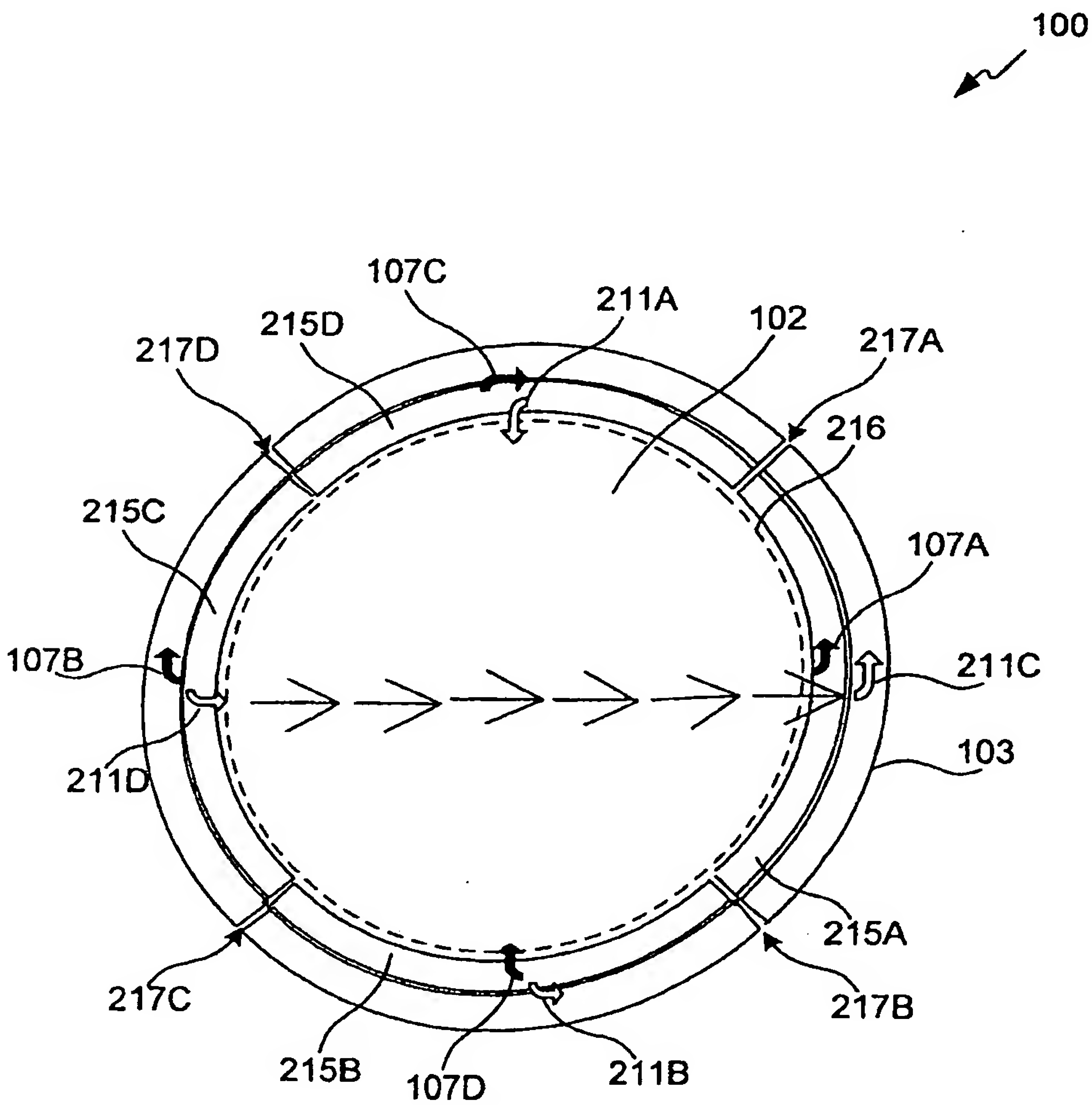


图1



100
107C
211A
102
217A
215D
217D
216
215C
107A
107B
211C
211D
103
215A
217C
217B
215B
107D
211B

图2

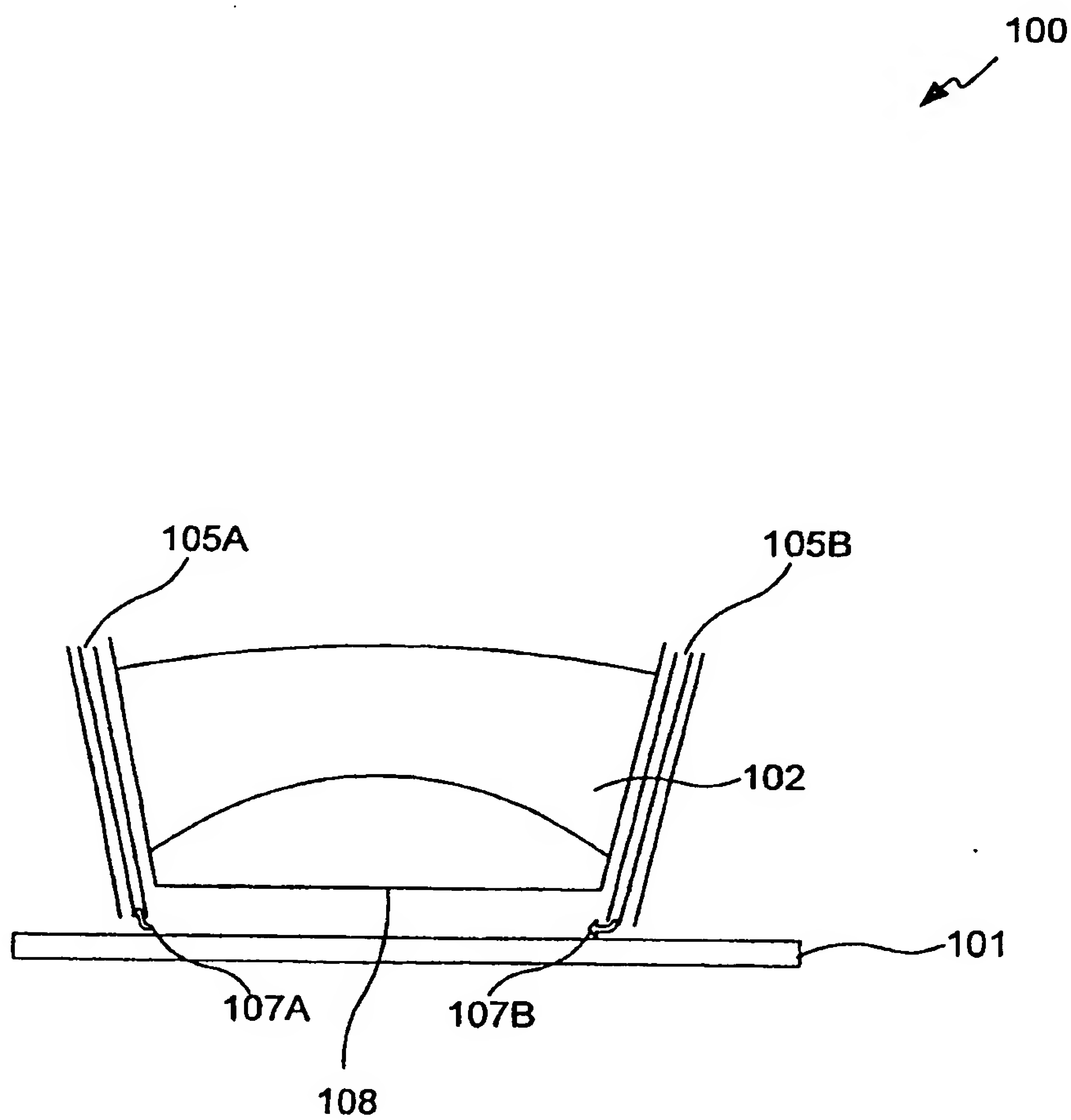


图3

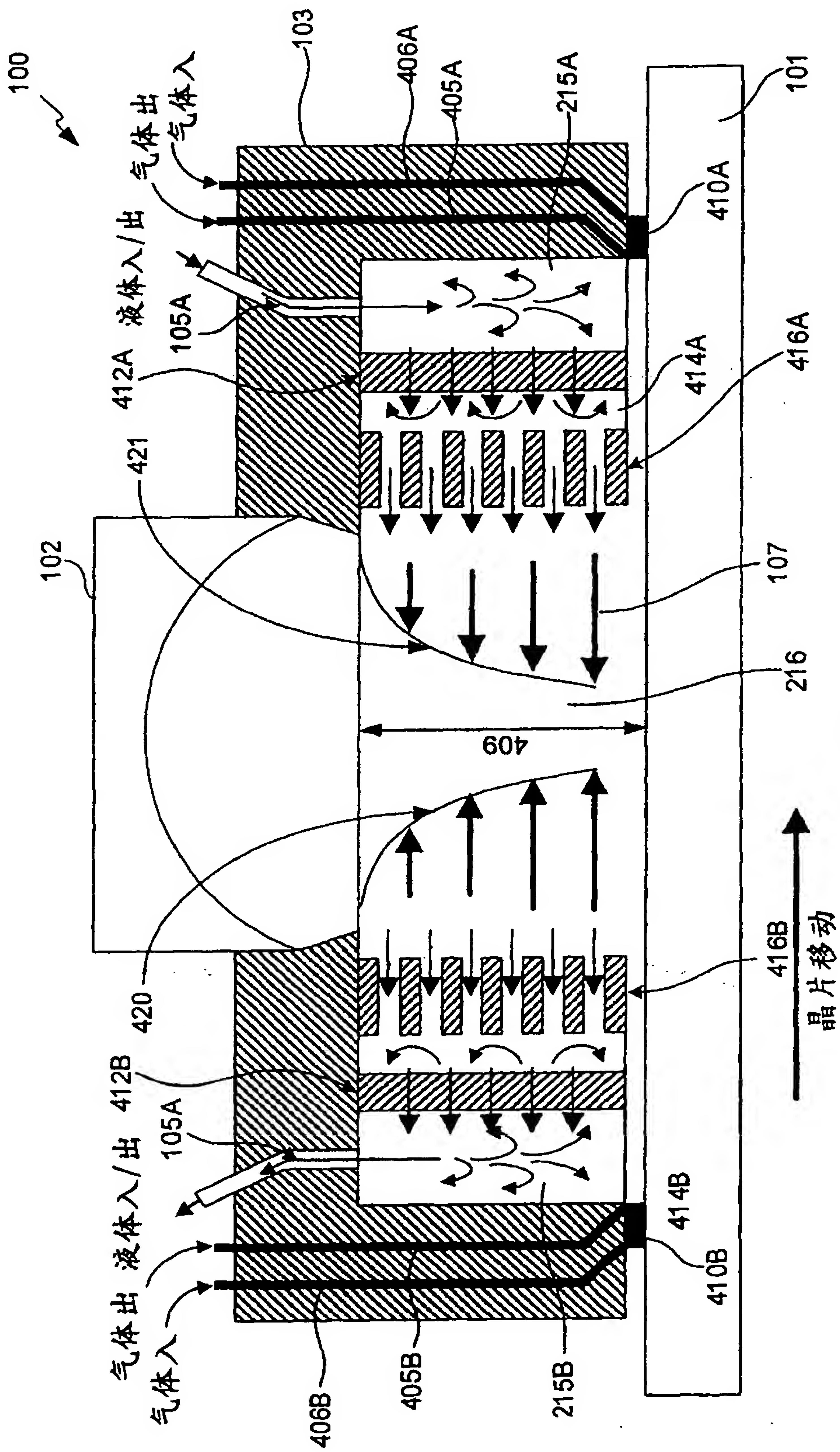

100
103
406A
405A
215A
101
气体出
气体入
液体入/出
105A
410A
412A
414A
416A
421
102
107
216
409
420
412B
105A
416B
414B
410B
406B
405B
215B
晶片移动

图4

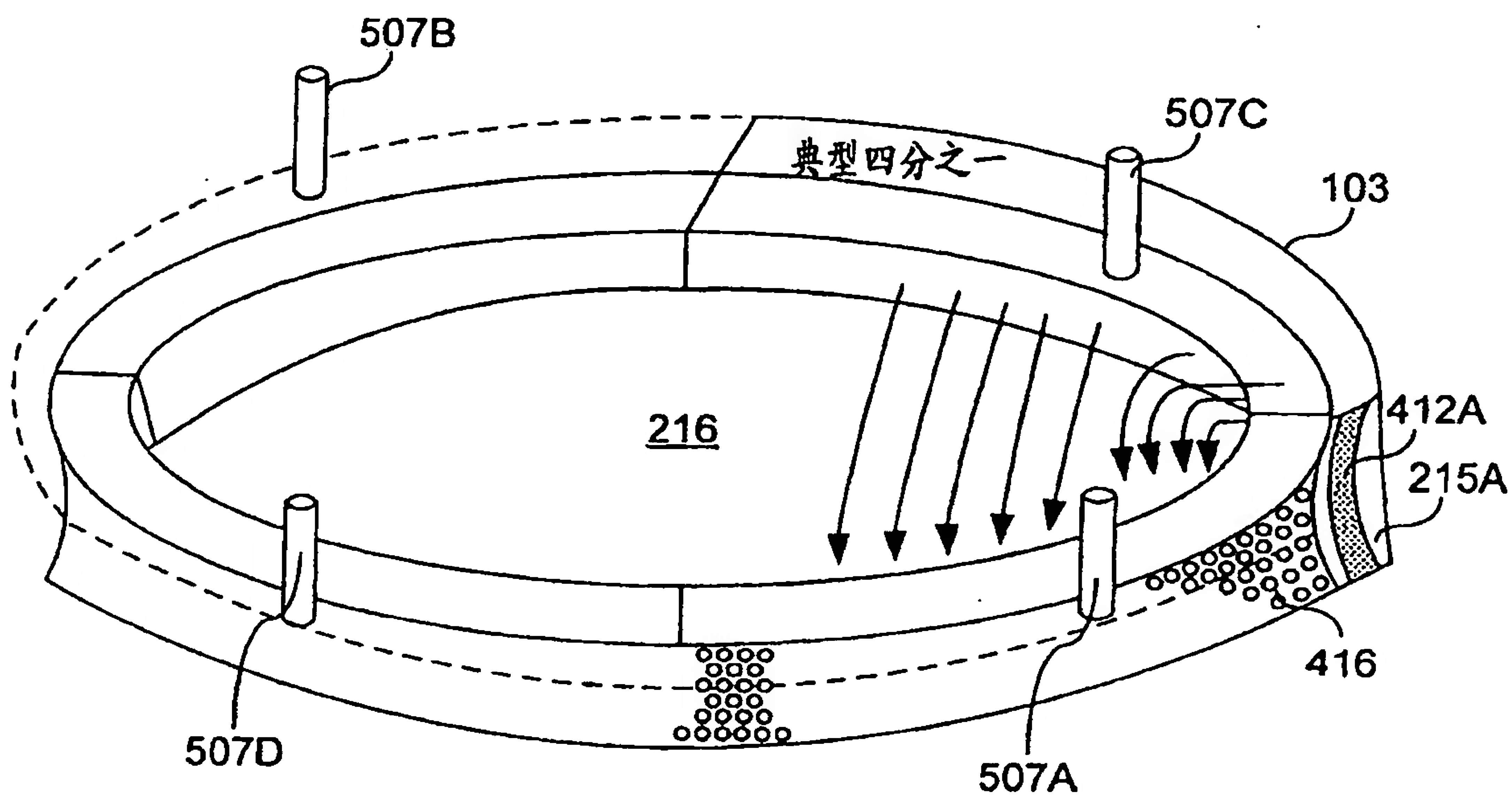


图5

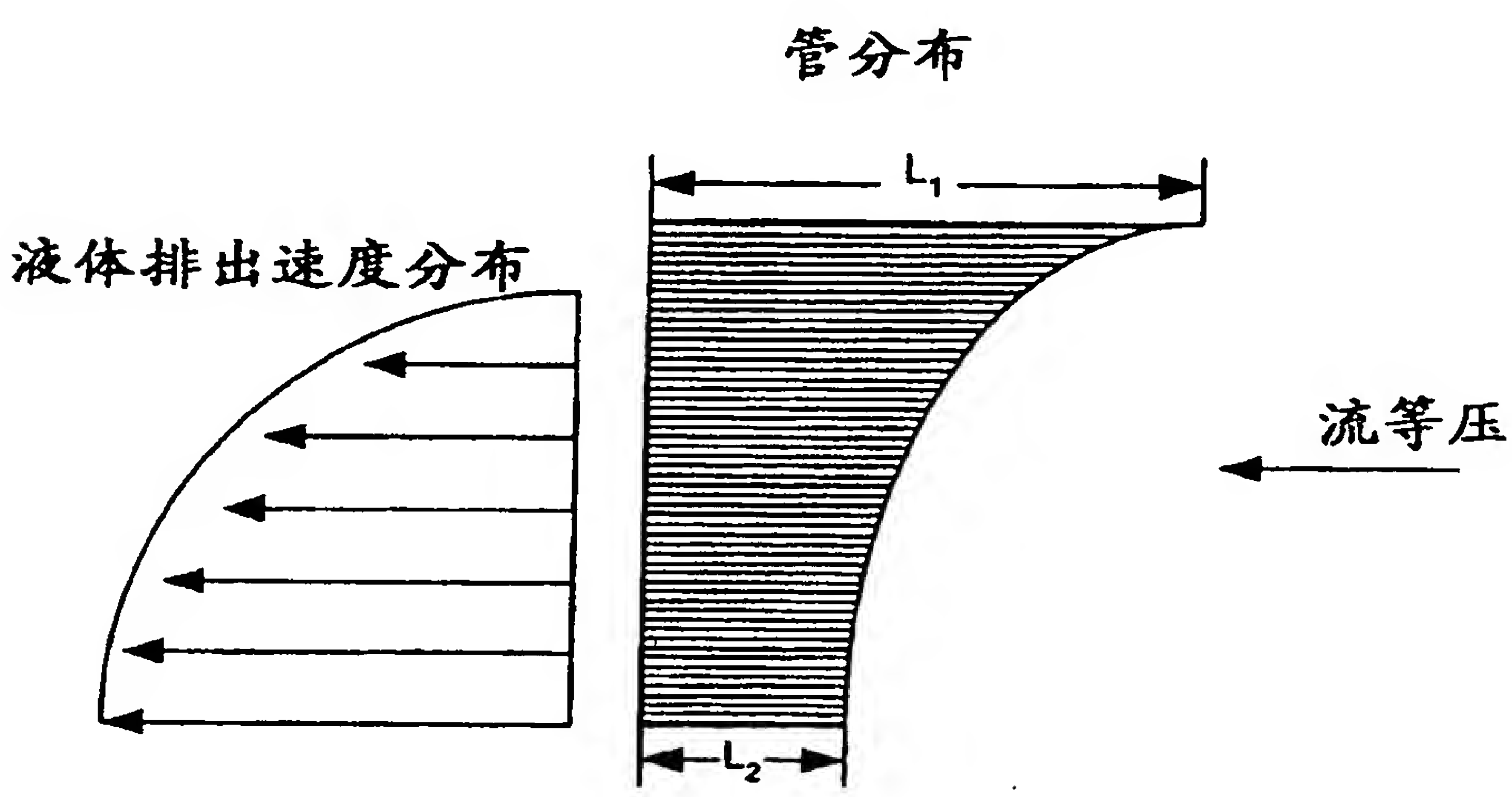


图6

BIBLIOGRAPHIC DATA

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[54] Invention Title:

Immersion photolithography system and method using microchannel nozzles

[57] Abstract for Disclosure

A liquid immersion photolithography system comprising: an exposure system that exposes a substrate with electromagnetic radiation and includes a projection optical system that focuses the electromagnetic radiation on the substrate; liquid supply system that provides liquid flow between the projection optical system and the substrate; and a plurality of micronozzles arranged around a periphery of the projection optical system so as to provide a substantially uniform velocity distribution of the liquid flow between the substrate and the projection optical system.

THE CLAIMS

1. A liquid immersion photolithography system comprising:

an exposure system that exposes a substrate with electromagnetic radiation and includes a projection optical system that focuses the electromagnetic radiation on the substrate;

a liquid supply system that provides liquid flow between the projection optical system and the substrate; and

a plurality of micronozzles arranged around a periphery of the projection optical system so as to provide a substantially uniform velocity distribution of the liquid flow between the substrate and the projection optical system.

2. The liquid immersion photolithography system of claim 1, wherein the plurality of micronozzles include a plurality of tubes of varying lengths.

3. The liquid immersion photolithography system of claim 1, wherein the varying lengths of the tubes provide a velocity profile that compensates for non-uniformities.

4. The liquid immersion photolithography system of claim 1, wherein the liquid supply system includes:

an input channel for delivering the liquid into a first plenum;

a first diffuser screen through which the liquid can flow into a second plenum,

wherein the liquid can then flow into the micronozzles.

5. The liquid immersion photolithography system of claim 4, wherein the liquid supply system further comprises:

a second plurality of micronozzles removing the liquid from the exposure area into a third plenum;

a second diffuser screen through which the liquid flows into a fourth plenum; and

an output channel through which the liquid is circulated.

6. The liquid immersion photolithography system of claim 1, wherein the projection optical system includes a housing with a gas seal between the housing and the substrate.

7. The liquid immersion photolithography system of claim 6, wherein the housing includes a plurality of annular channels connected to the gas seal through which negative pressure is maintained around the exposure area so as to remove stray liquid.

8. The liquid immersion photolithography system of claim 1, wherein the micronozzles are between 5 microns and 5 millimeters in diameter.

9. The liquid immersion photolithography system of claim 1, wherein the micronozzles are slit-shaped.

10. The liquid immersion photolithography system of claim 1, wherein at least some of the micronozzles include a portion that flares out into an area between the substrate and the projection optical system.

11. The liquid immersion photolithography system of claim 1, wherein a direction of the liquid flow is reversible.

12. The liquid immersion photolithography system of claim 1, wherein the liquid supply system includes at least three channels through which liquid can flow.

13. The liquid immersion photolithography system of claim 1, wherein the liquid supply system compensates for non-uniformities in a velocity profile.

14. A liquid immersion photolithography system comprising:

an exposure system that exposes an exposure area on a substrate with electromagnetic radiation and includes a projection optical system;

means for providing a liquid flow between the projection optical system and the exposure area; and

a first microshower at one side of the projection optical system that provides the liquid flow having a desired velocity profile when the liquid flow is present in the exposure area.

15. The liquid immersion photolithography system of claim 14, wherein the microshower includes a plurality of tubes of varying lengths.

16. The liquid immersion photolithography system of claim 15, wherein the varying lengths of the tubes provide a velocity profile that compensates for non-uniformities.

17. The liquid immersion photolithography system of claim 14, further comprising a liquid supply system that includes:

an input channel for delivering the liquid into a first plenum;

a first diffuser screen through which the liquid can flow into a second plenum,

wherein the liquid flows into the exposure area through the microshower.

18. The liquid immersion photolithography system of claim 15, wherein the liquid supply system further comprises:

a second microshower for removing the liquid from the exposure area into a third plenum;

a second diffuser screen through which the liquid can flow into a fourth plenum; and

an output channel through which the liquid can circulate out of the exposure area.

19. The liquid immersion photolithography system of claim 14, wherein the projection optical system includes a housing with a gas seal between the housing and the substrate.

20. The liquid immersion photolithography system of claim 19, wherein the housing includes a plurality of channels through which negative pressure is maintained around the exposure area so as to remove stray liquid.

21. The liquid immersion photolithography system of claim 14, wherein the microshower has micronozzles that are between 5 microns and 5 millimeters in diameter.

22. The liquid immersion photolithography system of claim 21, wherein at least some of the micronozzles include a portion that flares out into the exposure area.

23. The liquid immersion photolithography system of claim 21, wherein the micronozzles are slit-shaped.

24. The liquid immersion photolithography system of claim 14, wherein a direction of the liquid flow is reversible.

25. The liquid immersion photolithography system of claim 17, wherein the liquid supply system includes at least three channels through which liquid can flow.

26. The liquid immersion photolithography system of claim 14, wherein the microshower compensates for non-uniformities in the velocity profile due to scanning.

27. A liquid immersion photolithography system comprising:

an exposure system that exposes an exposure area on a substrate with electromagnetic radiation and includes a projection optical system; and

a liquid flow between the projection optical system and the exposure area having a velocity profile that compensates for relative motion of the exposure system and the substrate.

28. A liquid immersion photolithography system comprising:

an exposure system that exposes an exposure area on a substrate with electromagnetic radiation and includes a projection optical system; and

a plurality of micronozzles around a periphery of a lens of the projection optical system that provide a liquid flow in the exposure area.

29. A liquid immersion photolithography system comprising:

an exposure system that exposes a substrate with electromagnetic radiation and includes a projection optical system that focuses the electromagnetic radiation on the substrate; and

a liquid supply system that provides liquid flow between the projection optical system and the substrate,

wherein a direction of the liquid flow may be changed so as to compensate for direction of movement of the substrate.

30. The liquid immersion photolithography system of claim 29, further including a plurality of micronozzles arranged around a periphery of the projection optical system so as to provide a substantially uniform velocity distribution of the liquid flow between the substrate and the projection optical system.

31. The liquid immersion photolithography system of claim 30, wherein the plurality of micronozzles include a plurality of tubes of varying lengths.

32. The liquid immersion photolithography system of claim 31, wherein the varying lengths of the tubes provide a velocity profile that compensates for non-uniformities.

33. The liquid immersion photolithography system of claim 29, wherein the liquid supply system includes:

an input channel for delivering the liquid into a first plenum;

a first diffuser screen through which the liquid can flow into a second plenum,

wherein the liquid can then flow into the micronozzles.

34. The liquid immersion photolithography system of claim 33, wherein the liquid supply system further comprises:

a second plurality of micronozzles removing the liquid from the exposure area into a third plenum;

a second diffuser screen through which the liquid flows into a fourth plenum; and

an output channel through which the liquid is circulated.

35. The liquid immersion photolithography system of claim 29, wherein the liquid supply system compensates for non-uniformities in a velocity profile.

36. A method of exposing a substrate comprising:

projecting electromagnetic radiation onto the substrate using a projection optical system;

delivering a liquid flow between the projection optical system and the substrate; and

controlling a velocity profile of the liquid flow to as to provide a substantially uniform velocity profile.

37. The method of claim 36, further comprising the step of removing excess liquid from the substrate using a gas supply system.

38. The method of claim 36, further comprising the step of reversing direction of the liquid flow.

39. A method of exposing a substrate comprising:

projecting electromagnetic radiation onto the substrate using a projection optical system;

delivering a liquid flow between the projection optical system and the substrate; and

changing a direction of the liquid flow so as to compensate for a change in a direction of movement of the substrate.

40. The method of claim 39, further comprising the step of removing excess liquid from the substrate using a gas supply system

THE DESCRIPTION

Immersion photolithography system and method using microchannel nozzles

Field of the Invention

The present invention relates to liquid immersion photolithography, and more particularly, to a method and a system for controlling velocity profile of liquid flow in an immersion photolithographic system.

Description of the Related Art

The practical limits of optical lithography assume that the medium through which imaging is occurring is air. This practical limit is defined by the effective wavelength equation $A_{eff} = \frac{\lambda}{2 \cdot n \cdot NA}$ where λ is the wavelength of incident light, NA is the numerical aperture of the projection optical system, and n is the index of refraction of the medium. Now, by introducing a liquid (instead of the air) between a last lens element of the projection optical system and a wafer being imaged, the refractive index changes (increases), thereby enabling enhanced resolution by lowering the effective wavelength of the light source. Lowering a light source's wavelength automatically enables finer resolution of smaller details. In this way, immersion lithography becomes attractive by, for instance, effectively lowering a 157 nm light source to a 115 nm wavelength, thereby gaining resolution while enabling the printing of critical layers with the same photolithographic tools that the industry is accustomed to using today.

Similarly, immersion lithography can push 193 nm lithography down to 145 nm. In theory, older technology such as the 193 nm tools can

now still be used. Also, in theory, many difficulties of 157 nm lithography-large amounts of CaF2, hard pellicles, a nitrogen purge, etc. can be avoided.

However, despite the promise of immersion photolithography, a number of problems remain, which have so far precluded commercialization of immersion photolithographic systems. These problems include optical distortions. For example, during immersion lithography scanning, sufficient g-loads are created that can interfere with system performance. These accelerative loads can cause a vibrational, fluidic shearing interaction with the lens resulting in optical degradation. The up and down scanning motions within the lens-fluid environment of Immersion Lithography can generate varying fluidic shear forces on the optics. This can cause lens vibrational instability, which may lead to optical "fading". Other velocity profile non-uniformities can also cause optical distortions.

SUMMARY OF THE INVENTION

The present invention is directed to an immersion photolithography system with a near-uniform velocity profile of the liquid in the exposure area that substantially obviates one or more of the problems and disadvantages of the related art.

There is provided a liquid immersion photolithography system including an exposure system that exposes a substrate with electromagnetic radiation, and includes a projection optical system that focuses the electromagnetic radiation on the substrate. A liquid supply system provides liquid flow between the projection optical system and the substrate. A plurality of micronozzles are optionally arranged around the periphery of one side of the projection optical system so as to provide a substantially uniform velocity distribution of the liquid flow in an area where the substrate is being exposed.

In another aspect there is provided a liquid immersion photolithography system including an exposure system that exposes an exposure area on a substrate with electromagnetic radiation and includes a projection optical system. A liquid flow is generated between the projection optical system and the exposure area. A microshower is at one side of the projection optical system, and provides the liquid flow in the exposure area having a desired velocity profile.

Additional features and advantages of the invention will be set forth in the description that follows. Yet further features and advantages will be apparent to a person skilled in the art based on the description set forth herein or may be learned by practice of the invention. The advantages of the invention will be realized and attained by the structure particularly pointed out in the written description and claims hereof as well as the appended drawings.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are intended to provide further explanation of the invention as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS/FIGS.

The accompanying drawings, which are included to provide a further understanding of the exemplary embodiments of the invention and are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and together with the description serve to explain the principles of the invention. In the drawings:

FIG. 1 shows a side view of a basic liquid immersion photolithography setup.

FIG. 2 shows a plan view of the setup of FIG. 1.

FIG. 3 shows the basic liquid immersion photolithography setup with liquid flow direction reversed, compared to FIG. 1.

FIG. 4 shows additional detail of the liquid immersion

photolithography system.

FIG. 5 shows a partial isometric view of the structure of FIG. 4.

FIG. 6 shows an exemplary liquid velocity profile.

DETAILED DESCRIPTION OF THE INVENTION

Reference will now be made in detail to the embodiments of the present invention, examples of which are illustrated in the accompanying drawings.

One major problem in immersion photolithography is the non-uniformity of the liquid flow, particularly its gradient in the vertical direction. The non-uniformity is due primarily to the fact that near a moving surface, the liquid is in contact with that surface (e.g., a surface of a wafer). For example, during scanning, the wafer moves relative to the exposure system, creating a "dragging effect" near its surface. Thus, the laws of fluid dynamics dictate that the fluid velocity relative to the wafer surface is zero in those areas (or at least close to zero), while fluid velocity is maximum further away from the wafer surface. Similarly, the fluid velocity relative to the bottom surface of the lens is zero. These fluid velocity variations are known as "boundary layer" velocity profiles. The combination of these effects produces a shearing force in the liquid that creates a twofold optical distortion problem: 1) the generation of inertial vibrational forces upon the aperture hardware (resulting in optical distortion), and 2) the formation of velocity striations within the fluid, which cause additional optical distortions.

Additionally, injection of liquid into the exposure area also provides a liquid flow with potential additional non-uniformities in the velocity distribution. For example, a number of striations can exist within the fluid, further degrading exposure quality. Similarly, air bubbles, opto-fluidic vibrations, or turbulence in the liquid flow also can degrade the overall performance of the photolithographic system because of the introduction

of optical distortions into the exposure process. Thus, dealing with velocity profile non-uniformities is important from the perspective of the quality of imaging in a photolithographic system. In the ideal case, the velocity profile of the liquid is substantially uniform everywhere.

FIG. 1 illustrates a liquid immersion photolithographic system of the present invention in a block diagram form. As shown in FIG. 1, a projection optical system 100 of a photolithographic tool includes a lens 102 (which is typically comprised of multiple lens elements). In this figure, the lens 102 has a flat bottom surface 108, although that need not be the case. Lens height 409 (see FIG. 4) may be adjustable to maintain a specific distance to the wafer 101.

The projection optical system 100 also includes a housing 103 (only the lower portion is shown). The housing 103 includes an annular liquid channel 105A, and optionally a plurality of other such channels 105B, etc. Liquid flows through the channels 105 (flowing in through the channel 105A in this figure, and flowing out through the channel 105B). The arrows 107A, 107B designate the direction of liquid flow over a wafer 101, as the wafer 101 is being scanned across a field of view of the projection optical system 100.

FIG. 2 illustrates a bottom-up view of the structure shown in FIG. 1. As shown in FIG. 2, a clear aperture area 216 defines an exposure area of the projection optical system 100 and the lens 102. The various arrows 107A-107D, 211A-211D illustrate possible liquid flow directions at any given time. As may be further seen in FIG. 2, the housing 103 also includes a number of pressurized chambers 215A-215D. Each pressurized chamber 215 may also be referred to as a "plenum." The plenum 215 therefore acts as a pressure source, as discussed below. It will also be appreciated that the liquid flow can be turned off completely when no exposure is taking place, or when the wafer 101 is being swapped.

Further, as shown in FIG. 2, the lower portion of the housing 103 may be divided into a number of sections. In this figure, there are four such sections (quadrants), separated by gaps 217A-217D. It will be appreciated that the number of such sections may be more or fewer than four, although, in most applications, it is expected that four quadrants is an optimal number. For example, for motion only along one axis, dividing the housing 103 into two sections may be sufficient. For X-Y motion, four sections (quadrants) are preferred. For even greater control, eight sections may be needed. This sectioning permits control over liquid flow direction, as also discussed further below. Controlling the direction of liquid flow makes it possible to counteract mechanical strains on the lens 102, therefore the flow profile in the X direction (especially during a step) may be different from the flow profile in the Y direction (especially during a scan).

FIG. 3 illustrates the same structure as in FIG. 1, except that the direction of the liquid flow is reversed. As will be appreciated by one of ordinary skill in the art, the ability to reverse the direction of liquid flow is important in a practical photolithographic system, since the direction of wafer motion is normally not limited to just one direction. Similarly, it will be appreciated by one of ordinary skill in the art that, as in FIG. 2, the wafer 101 can move both in the X direction and the Y direction. Thus, dividing the housing 103 into quadrants permits the direction of liquid flow to be adjusted for any direction of wafer movement.

FIG. 4 illustrates an embodiment of the present invention in additional detail. As shown in FIG. 4, the lens 102 is mounted in the housing 103. The housing 103 has the annular channels 105A, 105B, through which liquid flows in and out from a liquid supply system (not shown in these figures). From the channel 105A, the liquid then enters a first large plenum 215A. It then flows through a diffuser screen 412A,

into a first small plenum 414A (which is typically smaller than the first plenum 215A). The diffuser screen 412A helps remove the turbulence and air bubbles that may be present in the first large plenum 215A. The diffuser screen 412 also acts as a pressure drop screen.

The first small plenum 414A also acts as a pressure chamber. From the first small plenum 414A, the liquid then flows through a plurality of microchannel nozzles (micronozzles) 416A, arranged in a form of a microshower. Thus, by the time the liquid reaches the micronozzles 416, the pressure at the entry to all the micronozzles 416 is uniform, and turbulence and gas bubbles have been substantially removed from the liquid. After the micronozzles 416, the liquid flows into the clear aperture area 216 under the lens 102, such that the space between the lens 102 and the wafer 101 is filled with the liquid.

In the clear aperture area 216, the liquid flow is uniform with height, and free of turbulence, bubbles, striations and other imperfections that affect optical image quality.

On the other side of the clear aperture area 216, the liquid once again flows through a set of microchannel nozzles 416B, into a second small plenum 414B, through a diffuser screen 412B, into a second large plenum 215B and out through the channel 105B.

Thus, with the relative motion of the wafer 101 from left to right in FIG. 4, the wafer 101 creates a "dragging effect" on the liquid. The direction of the liquid flow therefore needs to be from right to left, to counteract the "dragging effect," and result in substantially uniform velocity profile.

In FIG. 4, 420 designates effective fluid velocity profile within the clear aperture area 216 as induced by wafer 101 motion. 421 designates counter-injected fluid velocity profile from the microchannel nozzles 416, yielding near net-zero resultant fluid velocity at the interface between the

lens 102 and the liquid in clear aperture area 216.

The microchannel nozzles 416 also refresh (i.e., replace) the working liquid from time to time (which may be necessary to prevent its disassociation over time, since exposure to intense electromagnetic radiation may break down the molecules of the liquid), so as to preclude thermal gradients from causing refractive distortions and image quality degradation. Avoiding dissociation of liquid (for example water) due to constant flow is another advantage. At the short exposure wavelength, water can dissociate at approximately 2.86 J/cm^{2}RT and normal P turns to $4.75*10^{-19}$J per molecule. At 193 nm with one photon carries $1.03*10^{-18}$ J. Additionally, keeping the liquid refreshed allows to maintain a constant temperature of the liquid. The liquid may be refreshed during exposure, or between exposures.

The micronozzles 416 also act as a buffer against inertial shearing forces between the optics and the liquid. Note that the shearing force is defined by the equation $F = A \cdot \mu \cdot \frac{dv}{dx}$ where A is the area, μ is a viscosity parameter, x is a distance variable, and v is the velocity. The shearing force is approximately 1 Newton in the case of a typical 100 micron gap between the wafer 101 and the lens 102. Neutralizing these shearing forces is accomplished by inertially dampening the relative accelerative motion between the lens 102 and fluid. This is accomplished by simply creating fluidic motion in a direction opposite to scanning. The microchannel nozzles 416 also act as a buffer against inertial shearing forces between the optics and fluid.

Additionally, the housing 103 includes a system for supplying gas to remove any excess liquid from the wafer 101. The housing 103 includes a supply side annulus 406A for gas inflow from a gas supply system (not shown in FIG. 4), a gas seal 410A, which bridges the distance to the

wafer 101 and makes a "squeegee" so as to contain and remove any excess liquid, and a return side gas outflow annulus 405A (through which excess liquid is removed). The excess liquid may be removed through the return side gas outflow annulus 405A, together with the exhausted gas. A similar structure may be found in an opposite quadrant of the housing 103, as shown on the left side of FIG. 4. The gas supply system works in conjunction with the liquid supply system, whenever there is liquid flow present, and, consequently, need only be turned on when there is liquid flow in the clear aperture area 216.

As noted above, in FIG. 4, with the wafer movement from left to right, the liquid flow is "in" at channel 105A, and "out" at channel 105B. When the scan direction is reversed, the liquid flow reverses as well.

FIG. 5 shows a partial isometric view of the micronozzle structure area of FIG. 4. The channels 105A-105D (not shown in FIG. 5) are connected to outer tubes 507A-507D, through which liquid is supplied. Similarly, though not shown in this figure, the annuli 405, 406 may be connected to tubular gas couplings.

FIG. 6 illustrates an example of a liquid exhaust velocity profile that may be used in the present invention. As will be appreciated by one of ordinary skill in the art, a "natural" velocity profile is not uniform with height in FIG. 4, but rather may have a vertical gradient, which can cause optical distortion. To compensate for this natural gradient, different lengths of tubes (micronozzles 416) may be used, as shown in FIG. 6. In FIG. 6, the micronozzle length ranges from a maximum of L1 to a minimum of L2, resulting in approximately the velocity profile at the exit of the micronozzles 416 shown on the left of FIG. 6. The longer the micronozzle 416, the lower the output velocity of the liquid from that particular micronozzle. Furthermore, the micronozzles 416 themselves may have different diameters, if needed to further control the velocity

profile. Note further that the tubes of the micronozzles 416 need not necessarily be parallel to the wafer 101, to further control the velocity profile.

The height of the liquid above the wafer 101, in a typical system, is approximately 100 microns. Greater height generally results in a need for more micronozzles in 416A due to a larger volume in which velocity profile needs to be controlled.

Thus, with careful selection of the lengths, diameters and orientations of the micronozzles 416, the velocity profile in the clear aperture area 216 of the wafer 101 may be controlled, resulting in a substantially uniform velocity profile throughout the clear aperture area 216, thereby improving exposure quality. In essence, the velocity profile generated by a structure such as shown in FIG. 6 may be "opposite" of the "natural" profile that would exist otherwise. Thus, the characteristics of the micronozzles 416 are tailored to result in a substantially uniform velocity profile.

During scanning, the wafer 101 moves in one direction, while the liquid is recirculated and injected in the opposite direction. The effect of the present invention is therefore to neutralize the liquid velocity profile induced by the scanning motion, causing inertial dampening between the lens 102 and the liquid. In other words, the net effect is a "zero" net inertia and velocity profile steering away from motion. Depending on the direction of the liquid flow, either a reduction or elimination of shear forces, or a reduction in optical distortions may result. Thus, the immersion lithographic process is capable of performing at peak levels due to constant fluid refresh, avoidance of gas bubbles, and the buffering of opto-fluidic vibrations.

Note further that while the liquid in the plenum 215 may have turbulence and gas bubbles, by the time it travels through the diffuser

screen 412, the flow is uniform. Therefore, after passing through the diffuser screen 412, the plenum 414, and exiting from the micronozzles 416, the liquid flow has a desired velocity profile, substantially without imperfections caused by striations, opto-fluidic vibrations, turbulence, gas bubbles, and other non-uniformities, resulting in improved image quality.

As noted above, the bottom surface 108 of the lens 102 need not be flat. It is possible to use a lens 102 with a curved bottom surface 108, and compensate for any induced velocity profile non-uniformities with an appropriate arrangement of micronozzle lengths, diameters, and orientations, to result in a near-uniform velocity profile.

The micronozzles 416 may be constructed using conventional lithographic techniques on silicon material. On a microscopic scale, the micronozzles 416 resemble a honeycomb material composed of tubes that are stacked in a staggered formation that exhibits key characteristic dimensions of hydraulic diameter and length. The micronozzles 416 may be flared out into the clear aperture area 216.

Typical tubular diameters of the micronozzles 416 may vary, for example, from a few microns to tens of microns (e.g., 5-50 microns), and in some cases, up to 5 mm in diameter, and lengths of between about 10 to 100 diameters. Other lengths and/or diameters may be used. Slits, rather than round nozzles, may also be used. The number of micronozzles per unit area may also be varied.

For 193 nanometer imaging, the liquid is preferably water (e.g., de-ionized water), although other liquids, for example, cycle-octane, Krypton® (Fomblin oil) and perfluoropolyether oil, may be used.

The present invention results in a number of benefits to a liquid immersion photolithographic system. For example, in a step and scan system, transmission is improved, and there is less distortion. Dust particles in the air cannot enter the clear aperture area 216 between the

lens 102 and the wafer 101, since the liquid itself does not contain any dust, and the presence of the liquid acts as a barrier to the dust being present in the clear aperture area 216 during exposure. Preferably, the liquid is brought in after the wafer 101 has been loaded onto a wafer stage, and removed before the wafer 101 is unloaded. This minimizes dust and particulate contamination. Additionally, other ways of keeping the liquid from spilling during wafer exchange are possible as well, and the present invention is not limited to just the approach described above.

The fluid velocity profile induced by the scanning motion is neutralized, causing inertial dampening between lens 102 and the shearing fluid. Aside from acting as inertial dampers, the micronozzles 416 serve to refresh the working fluid volume, thereby eliminating refractive distortions due to thermal gradients created by the light source. A side benefit of the micronozzles 416 is their ability to discourage the formation of gas-bubbles during volume refresh. Also, the size of these micronozzles 416 prevents the formation of gas-bubbles that plague more conventional refresh techniques. All of these benefits allow the use of generally existing photolithographic tools and wavelengths to define much smaller features on a semiconductor surface.

Conclusion

While various embodiments of the present invention have been described above, it should be understood that they have been presented by way of example, and not limitation. It will be apparent to persons skilled in the relevant art that various changes in form and detail can be made therein without departing from the spirit and scope of the invention.

The present invention has been described above with the aid of functional building blocks and method steps illustrating the performance of specified functions and relationships thereof. The boundaries of these functional building blocks and method steps have been arbitrarily defined

herein for the convenience of the description. Alternate boundaries can be defined so long as the specified functions and relationships thereof are appropriately performed. Also, the order of method steps may be rearranged. Any such alternate boundaries are thus within the scope and spirit of the claimed invention. One skilled in the art will recognize that these functional building blocks can be implemented by discrete components, application specific integrated circuits, processors executing appropriate software and the like or any combination thereof. Thus, the breadth and scope of the present invention should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

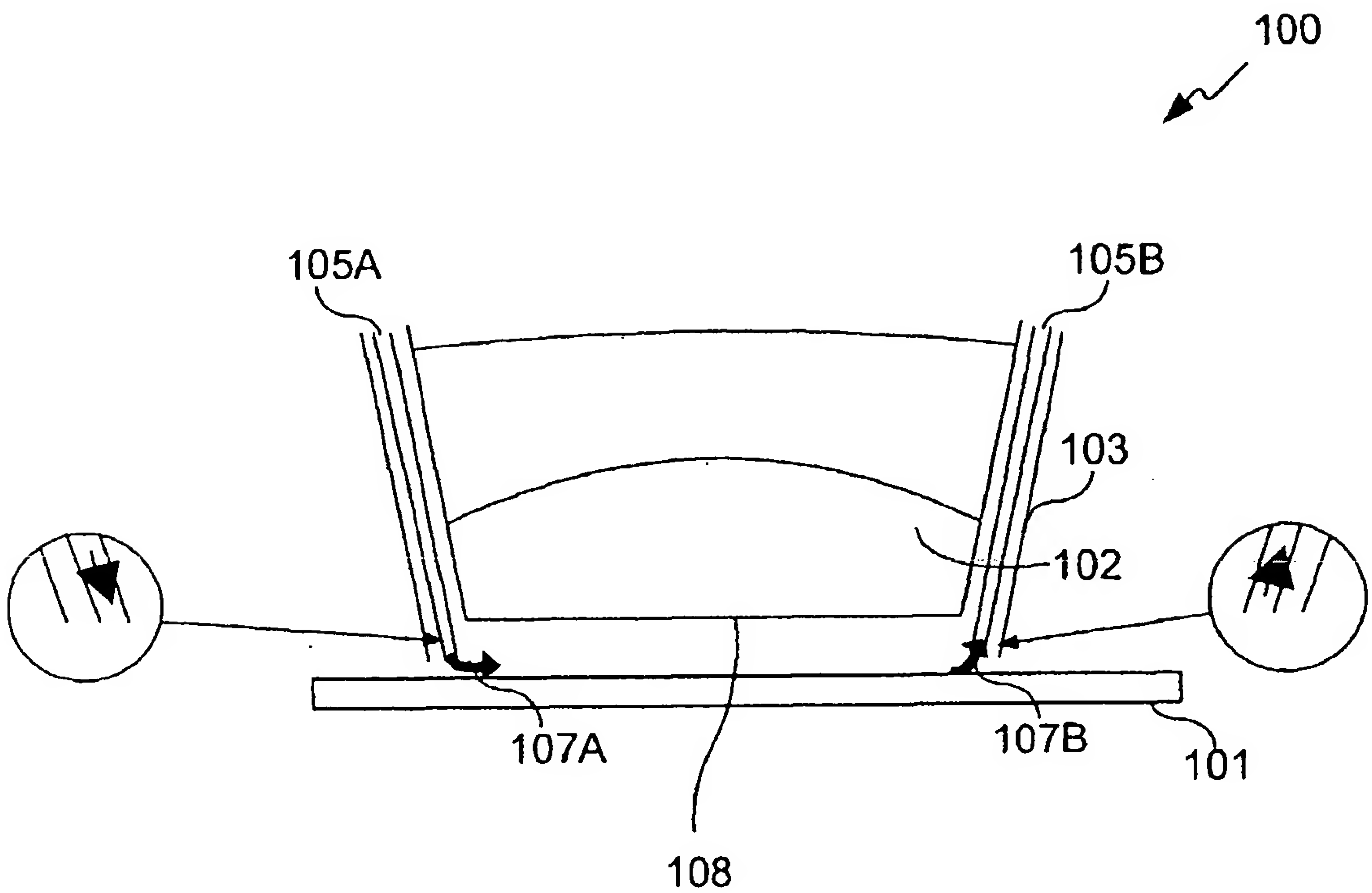

FIG. 1

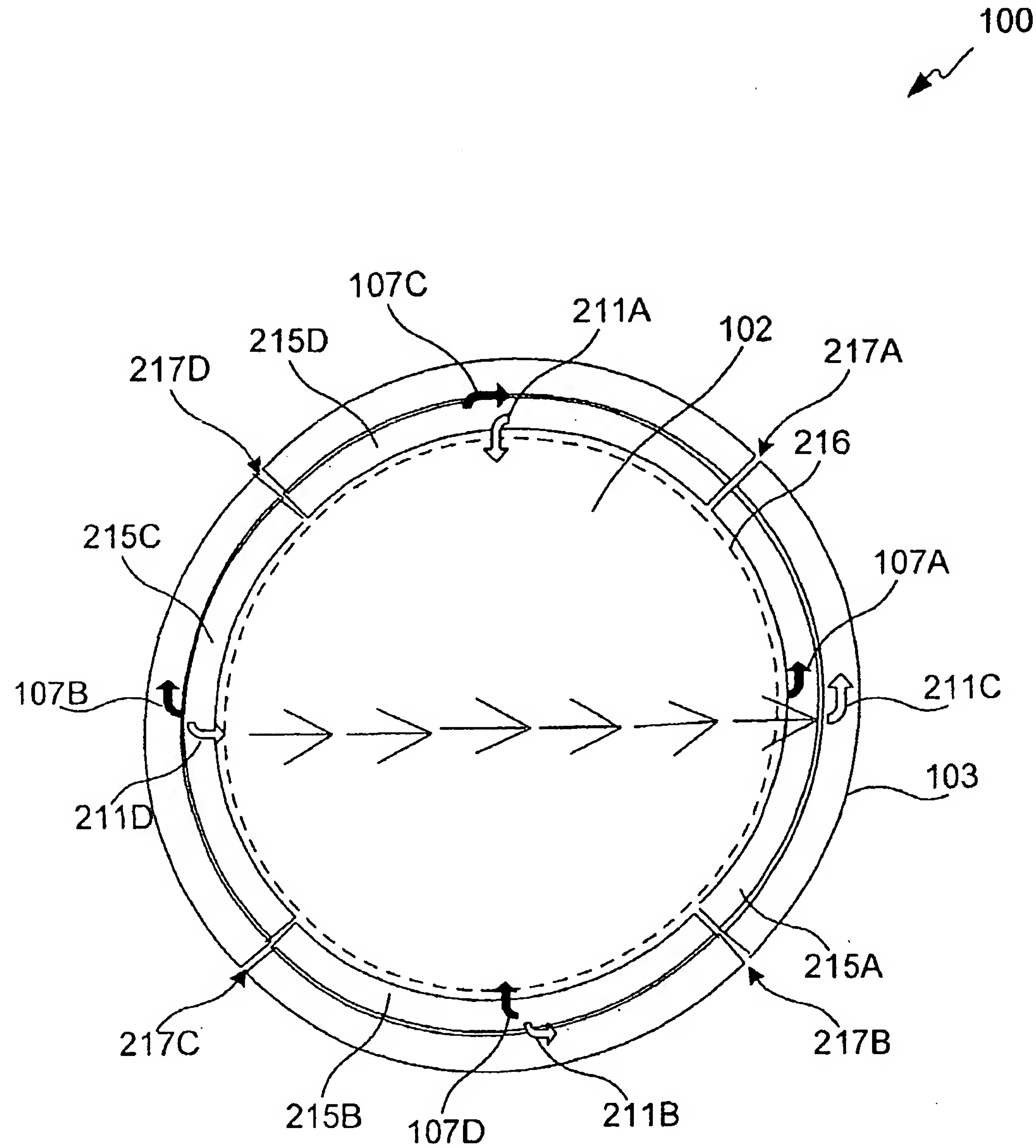
100
107C
211A
102
217A
215D
217D
216
215C
107A
107B
211C
103
211D
215A
217C
217B
215B
107D
211B

FIG. 2

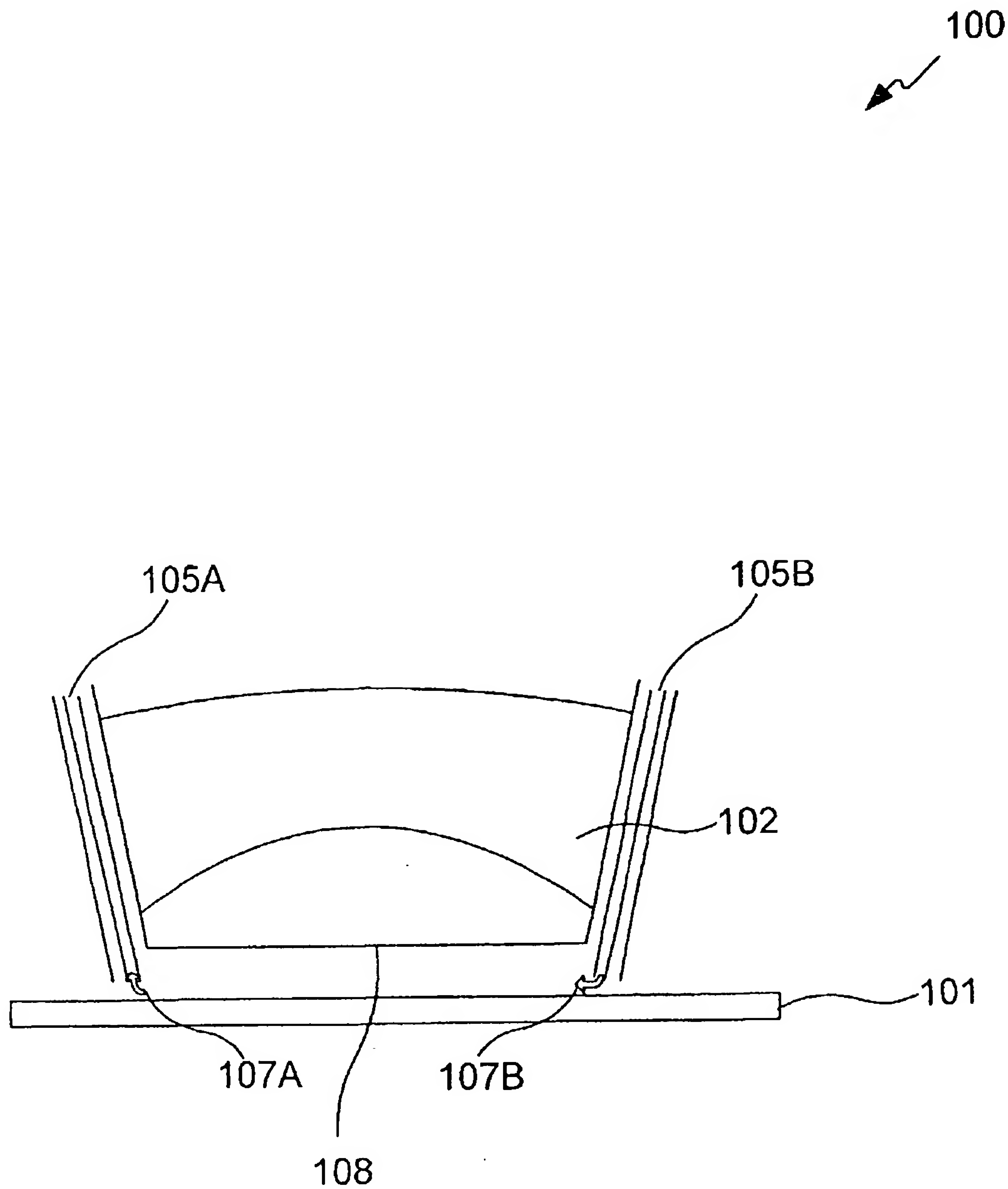

FIG. 3

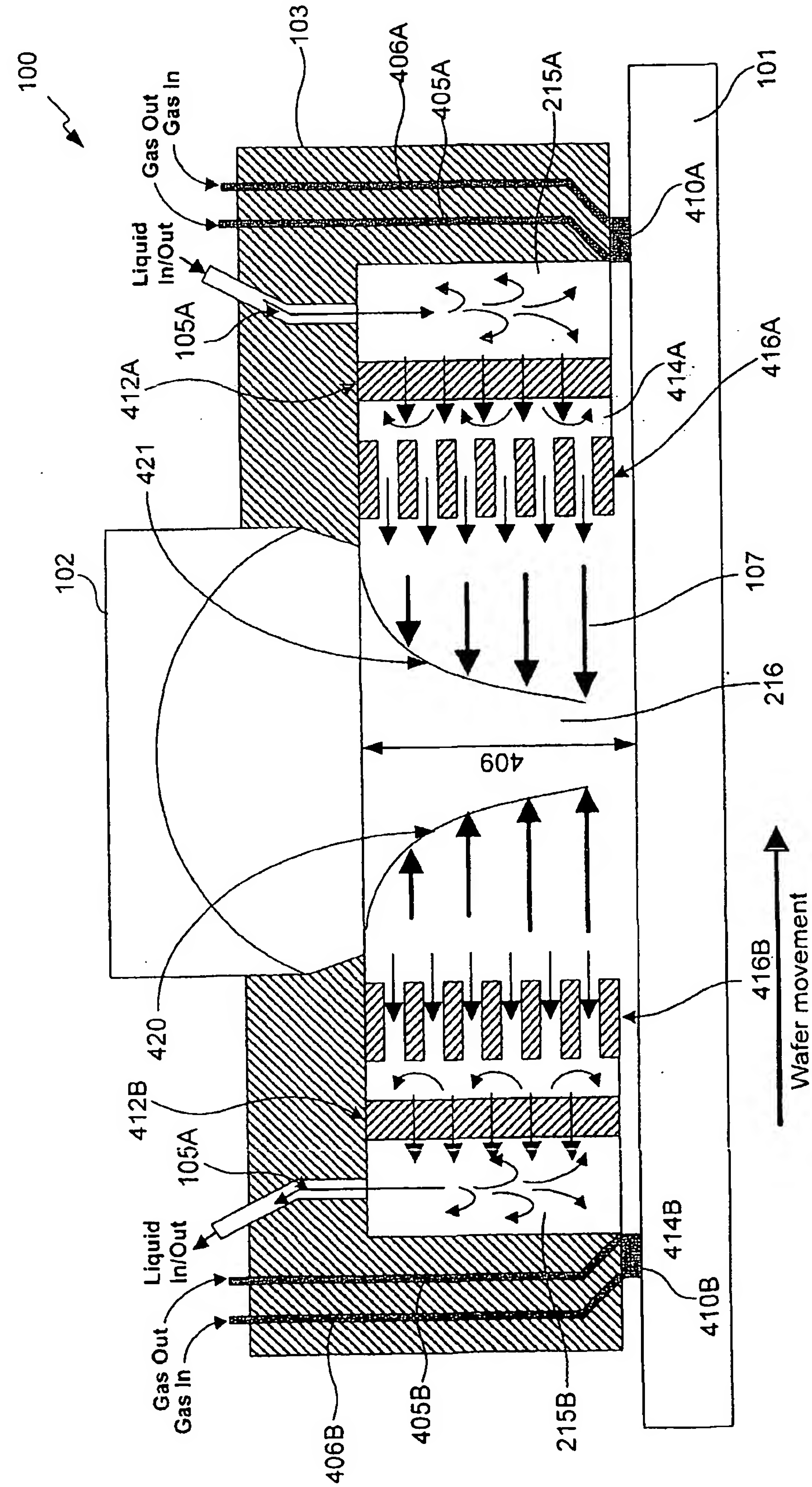
100
103
406A
405A
215A
101
Gas Out
Gas In
Liquid In/Out
410A
105A
412A
414A
416A
421
102
107
216
409
420
416B
Wafer movement
412B
105A
Liquid In/Out
414B
Gas Out
Gas In
410B
406B
405B
215B

FIG. 4

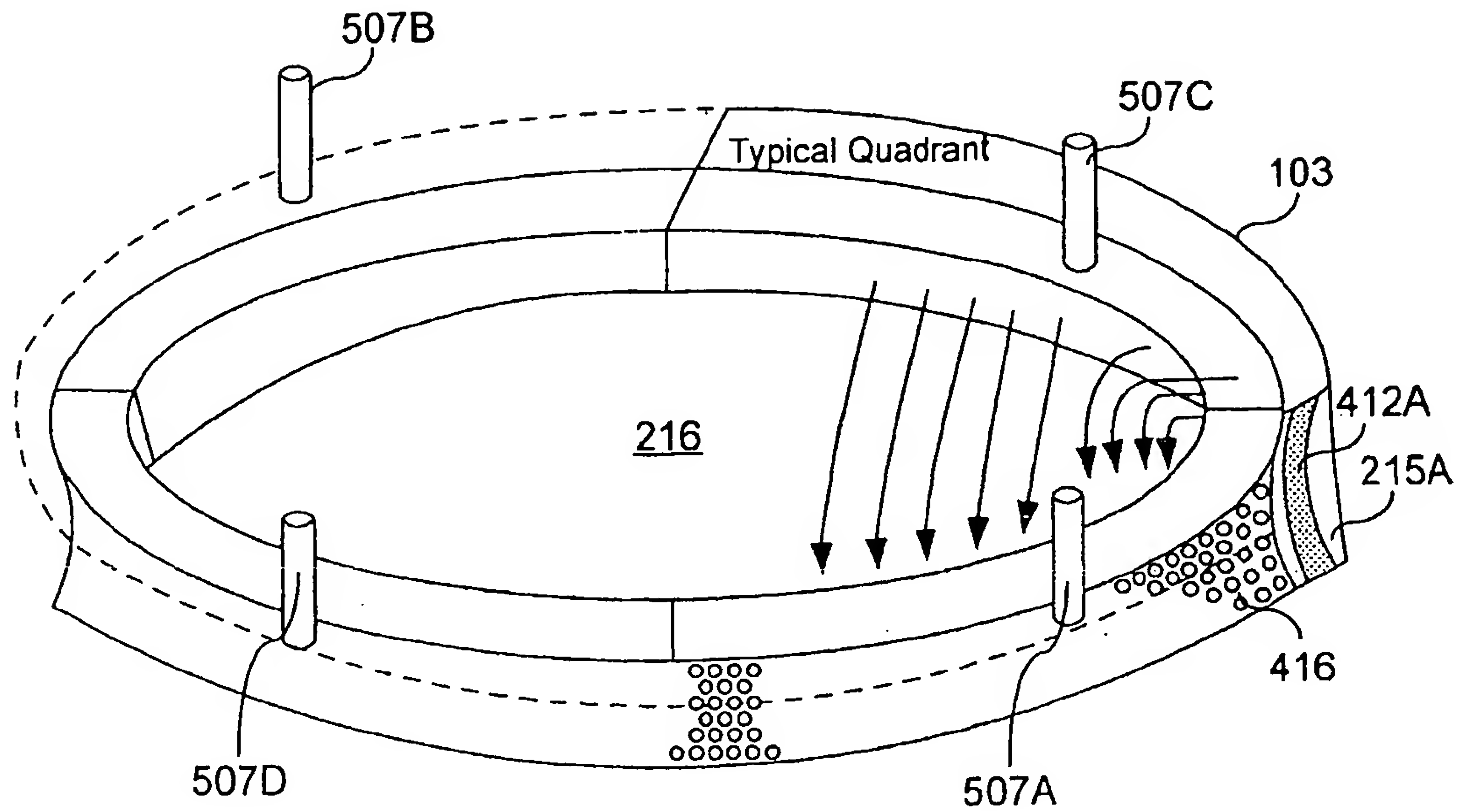

FIG. 5

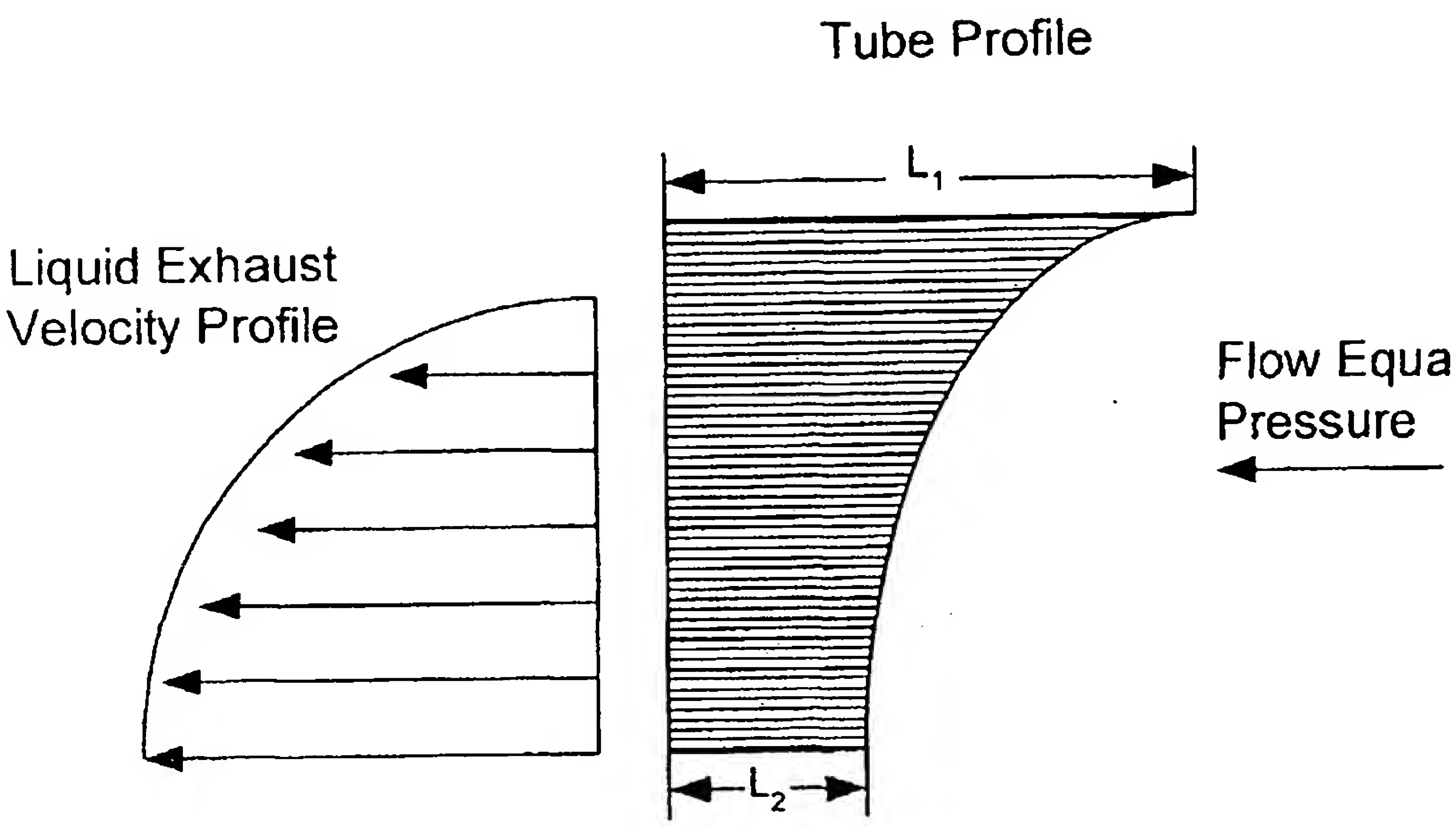
Tube Profile
L_1
Liquid Exhaust
Velocity Profile
Flow Equal
Pressure
L_2

FIG. 6